



(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
 29.01.1997 Bulletin 1997/05

(51) Int. Cl.⁶: **G01J 5/52, G01J 5/00**

(21) Application number: **96112107.6**

(22) Date of filing: **26.07.1996**

(84) Designated Contracting States:
AT BE CH DE ES FR GB GR IE IT LI NL SE

(72) Inventor: **Yam, Mark**
San Jose, California 95124 (US)

(30) Priority: **26.07.1995 US 506902**

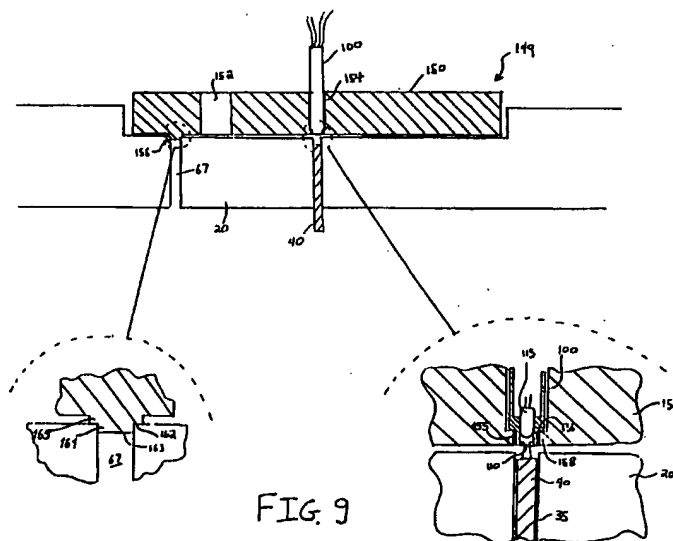
(74) Representative: **Kahler, Kurt, Dipl.-Ing.**
Patentanwälte,
Kahler, Käck, Fiener & Sturm,
Vorderer Anger 268
86899 Landsberg/Lech (DE)

(71) Applicant: **APPLIED MATERIALS, INC.**
Santa Clara, California 95052 (US)

(54) **A method and apparatus for Infrared pyrometer calibration in a thermal processing system**

(57) A calibration instrument (100) for calibrating a temperature probe (40, 50), such as pyrometer, uses a stable light source (115), such as a light emitting diode, to simulate a blackbody of a known temperature. The light source (115) is located inside a chamber and emits light through an aperture (110). The calibration instrument (100) may be inserted into a thermal processing

chamber, or the temperature probe may be removed from the chamber. An alignment tool (149) aligns the aperture (110) to the input of the temperature probe (40, 50). The calibration instrument may be integrated with the alignment tool, or it may be removable.



Description

Background of the Invention

The present invention relates to calibrating pyrometers that are used in thermal processing systems.

In rapid thermal processing (RTP), a substrate is heated quickly to a high temperature, such as 1200°C, to perform a fabrication step such as annealing, cleaning, chemical vapor deposition, oxidation, or nitridation. Particularly given the submicron dimensions of current devices, to obtain high yields and process reliability, the temperature of the substrate must be precisely controlled during these thermal processing steps. For example, to fabricate a dielectric layer 60-80 Å thick with a uniformity of ± 2 Å, which is typical of requirements in current device structures, the temperature in successive processing runs cannot vary by more than a few °C from the target temperature. To achieve this level of temperature control, the temperature of the substrate is measured in real time and *in situ*.

Optical pyrometry is a technology that is used to measure substrate temperatures in RTP systems. An optical pyrometer using an optical probe samples the emitted radiation intensity from the substrate, and computes the temperature of the substrate based on the spectral emissivity of the substrate and the ideal black-body radiation-temperature relationship.

When the system is first set up, the optical probe must be calibrated so that it produces a correct temperature reading when exposed to the radiation coming from the heated substrate. In addition, during repeated use, the temperature sensed by the probe might change over time and thus it will be necessary to recalibrate the probe or at least detect the change that has occurred so that corrective action can be taken. For example, the light pipe which is used to sample the radiation being emitted from the substrate as it is being heated, may become dirty or chipped, connections along the optical column transferring the sampled light to the pyrometer may loosen, or the electronic components in the pyrometer may "drift".

A commonly used method of calibrating the pyrometer is to use a special substrate or wafer in the chamber. The special substrate, which can be purchased from commercial sources, has a previously measured, known emissivity and it has an "embedded" thermocouple which is attached to the substrate with a ceramic material. When the substrate is heated, its actual temperature is indicated by the thermocouple. Since the substrate's emissivity is known, the radiation that is actually emitted by the substrate can be easily calculated by multiplying the intensity of radiation that would be expected from by an ideal black body that is at the predetermined temperature times the emissivity of the substrate. This is the radiation level that will be sampled by the optical probe of the pyrometer. The pyrometer is adjusted so that it produces a temperature reading that corresponds to the actual temperature.

Unfortunately, this method has drawbacks. The actual temperature of the substrate may in fact be different than the temperature measured by the thermocouple. First, the presence of the embedded thermocouple and the ceramic material causes the area with the thermocouple to have a different temperature than other parts of the wafer, i.e., it disturbs the temperature profile on the substrate. Second, at high temperatures (e.g., 1000°C as is commonly found in RTP processes) the joint between the wafer and thermocouple tends to degrade, so that after four or five uses the thermocouple readings become unreliable. Because of these shortcomings, this calibration technique cannot really guarantee pyrometer accuracy that is better than ten to fifteen °C.

In addition, there are difficulties associated with placing a thermocoupled substrate inside the chamber and making electrical connection to the thermocouple.

Summary of the Invention

In general, in one aspect, the invention features an apparatus for calibrating a temperature probe (e.g., a pyrometer). In the invention, a light emitting diode is held in a cavity of a calibration instrument and positioned to emit light through an aperture into an input end of the temperature probe. The calibration instrument emits light having a predetermined intensity. There is an indicia indicating a black-body temperature from that the light from the calibration instrument simulates.

In general, in another aspect, the invention features a method for calibrating a temperature probe. In the method, stable light of a predetermined intensity shines from a calibration instrument into an input end of the temperature probe. The stable light simulates radiation from a black body at a temperature T_0 . The temperature probe is used to produce a temperature reading T_1 in response to the light. The difference between T_0 and T_1 is used to generate corrected measurements from the temperature probe during processing within the thermal processing system.

In general, in another aspect, the invention features an apparatus for calibrating a temperature probe inside a thermal processing chamber. In the apparatus, an alignment tool has a light source having a stable intensity. The light source is held in a cavity and positioned to emit light through an aperture during calibration. A first alignment structure of the alignment tool engages a corresponding first alignment feature of the chamber. The aperture is located in a position relative to the first alignment structure so that during calibration the aperture is aligned with an input of the temperature probe.

Implementations of the invention may include the following features. The first alignment structure may comprise a pin and the first alignment feature may comprise a pinhole in a reflector plate in the chamber and located in proximity to the input end of the probe. The first alignment structure may comprise a projection adapted to fit a lift pin hole in a reflector plate in the

chamber. The cavity and aperture may be located in a body and the body may include a second alignment structure to engage a corresponding second alignment feature of the alignment tool. The body may be removable from the cavity. The body may be cylindrical, and the second alignment feature may comprise a cylindrical conduit having an annular lip. The alignment tool may be a disk and the second alignment feature may comprise a conduit through the disk.

In general, in another aspect, the invention features an apparatus for calibrating a temperature probe outside a thermal processing chamber. The apparatus features an alignment tool having a cavity and an aperture leading thereto. The alignment tool has an alignment structure to engage an input end of the probe. A light source having a stable intensity is held in the cavity and positioned to emit light through the aperture during calibration. The aperture is located in a position relative to the alignment structure so that during calibration the aperture is aligned with the input end of the probe.

In general, in another aspect, the invention features a method of calibrating a temperature probe inside a thermal processing chamber. In the method, an alignment tool having a cavity and an aperture leading thereto is inserted into the chamber. An alignment structure of an alignment tool engages an alignment feature of the chamber. Light having a stable intensity is emitted from the cavity, through the aperture, and into an input end of the probe.

In general, in another aspect, the invention features a method of calibrating a temperature probe outside a thermal processing chamber. In the method, an input end of the probe is removed from the chamber. An alignment structure of an alignment tool engages the input end of the probe. Light having a stable intensity is emitted from a cavity, through an aperture, and into an input end of the probe.

Among the advantages of the invention are the following. The pyrometer may be accurately (e.g., less than 1°C error) calibrated without using a wafer with an embedded thermocouple. Calibration may be performed more quickly and using less energy. Calibration may be traced to an absolute standard. The pyrometer may be calibrated without removing the light pipe from the chamber. The calibration instrument may be portable and sturdy.

Other features and advantages will be apparent from the following description and the claims.

Brief Description of the Drawings

Fig. 1 shows a rapid thermal processing chamber;
 Fig. 2 shows a calibration probe;
 Fig. 3 shows a temperature sensing probe;
 Fig. 4 is a graph of transmission of a filter and normalized light intensity of an LED, both as a function of wavelength;
 Fig. 5 shows a cross-section of a calibration probe;
 Fig. 6 is a circuit diagram of a calibration probe;

Fig. 7 is a top view of an alignment tool;

Figs. 8A and 8B are cross-sectional views of the alignment tool shown in Fig. 7 taken along lines A and B, respectively;

Fig. 9 shows a the alignment tool of Fig. 8 with a calibration probe mounted therein;

Fig. 10 shows of the light beam from a calibration probe;

Fig. 11 shows another embodiment of a calibration probe with an alignment tool attached thereto;

Fig. 12 shows yet another embodiment of a calibration instrument; and

Fig. 13 is a flow chart of a calibration procedure using the calibration instrument.

Description of the Preferred Embodiments

Before describing the details of a pyrometer calibration tool which is used to calibrate pyrometers within an RTP system, we will first describe an RTP system which includes the pyrometers that are to be calibrated. Referring to Figs. 1 and 2, in general an RTP system includes a processing chamber 60 for processing a disk-shaped, eight-inch (200 mm) diameter silicon substrate 10. The substrate 10 is held inside chamber 60 by a substrate support structure 62 and is heated by heating element 70 (e.g. an array of tungsten halogen lamps) located directly above the substrate. Heating element 70 generates radiation which enters chamber 60 through a water-cooled quartz window 72 located approximately one inch above substrate 10. Beneath substrate 10 is a reflector plate 20 which is mounted on a stainless steel base 65. Reflector plate 20 is made of aluminum and has a highly reflective surface coating 24 (e.g. a gold alloy). The underside of substrate 10 and the top of reflector plate 20 form a reflecting cavity 30 which makes the substrate appear more like an ideal black body, i.e., it produces an increased effective emissivity for the substrate.

A conduit 35 extending from the backside of base 65 through the top of reflector plate 20 holds a sapphire light pipe 40 which acts as the input probe of a temperature probe 15 that includes a pyrometer 50. An input end 22 of light pipe 40 is located near (e.g. flush with) the top of reflector plate 20 and samples radiation from reflecting cavity 30. Sampled radiation passes down light pipe 40, through a flexible optical fiber 45, and into pyrometer 50. The coupled ends of optical fiber 45 and sapphire light pipe 40 are held in close optical contact with each other by a threaded connector 42. There are a plurality of temperature probes 15 (e.g. eight) positioned in reflector plate 20 to sample radiation at different radii of the substrate.

In the described embodiment, sapphire light pipe 40 is about 0.05 to 0.125 inches in diameter (e.g. 0.080) and pyrometer 50 is a Luxtron Accufiber Model 100. A more complete description of an RTP system along with an explanation of how the reflecting cavity acts to produce a virtual black body may be found in U.S. Patent

Application Serial No. 08/359,302 filed December 19, 1994, and incorporated herein by reference.

Inside pyrometer 50, radiation from optical fiber 45 passes first through an optical filter 52 before falling onto a silicon detector 54 (e.g. photodiode). The signal from detector 54 is input to control electronics 56 which converts that signal to a temperature reading T_{out} which is used by power control circuitry (not shown) for the lamps. Control electronics 56 includes a lookup table (not shown) that it uses to convert the measured current into a output temperature reading T_{out} . The lookup table, which maps measured output signal to the corresponding temperature of an ideal black body can be readily derived from Planck's law, in a manner well known to persons skilled in the art. Control electronics 56 also includes a gain control terminal by which the gain of the control electronics may be adjusted during calibration so that pyrometer outputs an accurate temperature reading.

Referring to Fig. 3, in normal operation, the heating element 70, such as a lamp array, directs radiation to substrate 10. Some of that radiation (i.e., radiation 74) is absorbed by the substrate and some of it (i.e., radiation 75) is transmitted through the substrate into cavity 30. Substrate also emits radiation 76 the intensity of which is a function of the temperature of the substrate. Typically, a silicon wafer transmits radiation with a wavelength greater than about 1.0 microns; whereas, silicon detector 54 responds to radiation having a wavelength up to 1.5 microns. If transmitted radiation is permitted to reach silicon detector 54, it will produce an erroneous temperature reading. Therefore, to prevent transmitted radiation from reaching detector 54 and interfering with the temperature measurement, the bandpass characteristics of filter 52 are selected to prevent the transmitted radiation from the lamps from reaching the detector. In the described embodiment, filter 52 is glass coated with an optical stack, e.g., a quarter-wave stack, which transmits light in a narrow range of wavelengths (e.g. 0.89 to 0.93 microns) and has very high rejection above 1.0 microns. The transmission of filter 52 as a function of wavelength is shown by dashed line 52a in Fig. 4.

To calibrate the pyrometer, a special calibration instrument is used (see Figs. 9, 11, and 12). The calibration instrument includes a stable light source, such as a light emitting diode (LED), which emits radiation primarily in the narrow spectrum defined by filter 52. The stable light source simulates a black-body at a predetermined temperature. That is, it emits the same amount of radiation over the spectrum of interest as would a black body that is heated to the predetermined temperature. The calibration instrument, several embodiments of which are described below, aligns the light source with the input end of the sapphire light pipe so that a known and repeatable amount of radiation enters the sapphire light pipe during each calibration run.

The light source is constructed and/or selected to "match" filter 52. That is, its maximum output and its

spectral range coincide with the bandpass region of filter 52. Referring to Fig. 4, the characteristics of an LED that is used with the previously described filter 52 are shown by solid line 115a. The LED has an approximately gaussian spectral distribution which is about 0.2 microns wide with a maximum intensity at about 0.89 microns.

Referring to Fig. 5, a calibration probe 100 which simulates a black body at a known temperature includes a generally cylindrical body 102 having an internal cavity 104. One end of cylindrical body 102 is closed, except for a small channel 110 defining an aperture through which light can pass out of cavity 104. A light emitting diode (LED) 115 positioned in cavity 104 emits light that passes out through channel 110.

In the described embodiment, body 102 is a machined aluminum cylindrical tube, 0.3745 inches in diameter and 2.0 inches long. Channel 110 extending between a bottom surface 130 of body 102 and cavity 104 is about 0.02 inches in diameter by about 0.02 inches long and is centered on the axis of the cylindrical body 102. At the end of body 102 in which channel 110 is located there is a narrower cylindrical region 132 having a diameter of about 0.30 inches and a length of about 0.10 inches. A circular outer edge 134 of the cylindrical body 102 is beveled at a 45° angle to make it easier to insert the calibration probe into an alignment tool that is described below.

Since the light output of the LED 115 varies as a function of temperature, means are also provided to stabilize the temperature of the LED. In particular, calibration probe 100 also includes a small heating resistor 122, such as a fifty Ω resistor and a thermocouple 124, such as a K-type thermocouple, placed in close proximity to LED 115. Resistor 122 is used to heat the LED up to about 80°F, i.e., slightly above the expected ambient temperature. Alternatively, the LED could be cooled to a temperature below ambient. However, cooling would be a more difficult and costly alternative.

All three components (i.e., LED 115, thermocouple 124 and resistor 122) are secured in place by a thermally conductive ceramic 117, such as Azemco ceramicast 583. Ceramic 117 ensures that the heat from heater 122 is efficiently transmitted to LED 115 and thermocouple 124. Ceramic 117 also holds the position of LED 115 constant relative to channel 110 so that no changes in light intensity occur due to shifting or rotation of LED 115 inside cavity 104.

Referring to Fig. 6, a power supply 120 supplies a constant current to LED 115. In the described embodiment, power supply 120 uses a laser diode (not shown) in a manner well known to those skilled in the art to stabilize the current through LED 115 and thereby stabilize its light output. Alternatively, the output power of LED 115 can be stabilized by using a photodiode (not shown) positioned so as to sample the light output of LED 115. In that case, the photodiode is connected through a feedback circuit to current source 120 to produce a constant light output from LED 115.

Thermocouple 124 and heater 122 are connected to a proportional integrated device (PID) controller 126 to form a feedback circuit to stabilize the temperature of LED 115. By holding both the temperature of LED 115 and current through LED 115 constant, LED 115 gener-

ates radiation with a very stable intensity. During calibration, an alignment tool is used to align calibration probe 100 with the light pipe of the temperature probe being calibrated. We shall give examples of two design types for this alignment tool. One design type is used *in situ*. That is, it aligns calibration probe 100 with light pipe 40 without having to remove the light pipe from the system. The other design type is used to perform the calibration remotely. That is, light pipe 40 is removed from the RTP chamber and inserted into the alignment tool.

Referring to Figs. 7, 8A, 8B, and 9, an alignment tool 149 according to an embodiment which is used for *in situ* calibration is adapted to fit into the RTP chamber above the reflector plate. When inserted into the RTP chamber, alignment tool 149 holds the calibration probes in a fixed position relative to the light pipes. More specifically, alignment tool 149 is a circular disk 150 with an arrangement of holes 154 into which individual calibration probes 100 can be inserted. The number of holes 154 coincides with the number of thermal probes that are in the reflector plate. Holes 154 are located at different radii from the center of disk 150 and are positioned so that they coincide and are aligned with the locations of the conduits 35 in reflector plate 20 when alignment tool 149 is inserted into position within the chamber. As is shown most clearly in Fig. 9, at the bottom of each small hole 154 there is an annular lip 158 with a smaller diameter hole 155 in it. Hole 155 has a diameter that is slightly larger than the diameter of the narrower cylindrical region 132 at the bottom of calibration probe 102 and lip 158 has a thickness that is equal to the length of the narrower cylindrical region 132 on calibration probe 102. Thus, when calibration probe 102 is inserted into a hole 154, it comes to rest against lip 158 with its bottom surface 130 substantially flush with the bottom of disk 150 (i.e., flush with the surface of disk 150 that is proximate to the reflector plate when it is installed within the RTP chamber during a calibration).

In the described embodiment, alignment tool 149 is made of plastic or nylon, e.g. Delrin. It is about 1.0 inch thick and 8.9 inches in diameter. Each of holes 154 has an inside diameter of about 0.375 inches, which is slightly larger than the outside diameter of cylindrical body 102 so that calibration probe 100 can be easily inserted into the hole. Annular lip 158 is about 0.11 inches thick and projects inward by 0.047 inches, so that the inner diameter of smaller hole defined by annular lip 158 is about 0.328 inches.

Returning to Fig. 8, three projections 156 are located on the underside of disk 150. These projections 156 are spaced equidistant from each other around a circle with its center coinciding with the center of disk 150 and they are positioned so as to align with lift pin

holes located in the reflector plate in the RTP chamber when alignment tool 149 is inserted into the RTP chamber. As shown in Fig. 8A, each projection 156 has a cylindrical lower portion 161 with a first diameter and a cylindrical upper portion 165 with a larger second diameter to thereby form an annular step 162 at the point of transition from lower portion 161 to upper portion 165. The first diameter is slightly smaller than the diameter of the corresponding lift pin hole in the reflector plate and the second diameter is larger than the diameter of the lift pin hole. Annular step 162 is about 0.01 to 0.04 (e.g. 0.03) inches away from the bottom face of disk 150. Thus, when alignment tool 149 is inserted into the RTP chamber, lower portions 161 slide into their corresponding lift pin holes in the reflector plate and annular steps 162 hold the bottom face of disk 150 at a distance of about 0.03 inches above the surface of the reflector plate.

Disk 150 also includes three larger holes 152, each located at a short distance radially inward from a corresponding one of projections 156. These holes 152, which are about 0.75 inches in diameter, enable the user to see the location of the lift pins holes in the reflector plate when the alignment tool is being inserted into the RTP chamber. On the top side of disk 150, there is also a handle 160 with which the technician can lift and manipulate the disk as it is being inserted into the RTP chamber.

As shown in Fig. 10, calibration probe 100 is inserted into small hole 154. When the alignment tool is fully assembled into the RTP chamber, each small hole 154 and the calibration probe 100 which it contains will be aligned with a corresponding one of the sapphire light pipes 40. By inserting a calibration probe 100 into each of the eight holes 154, the eight pyrometers 50 may be calibrated simultaneously. Alternatively, a single calibration probe 100 can be used and moved from one hole to the next for each calibration.

When calibration probe 100 is positioned above a light probe by the alignment tool, there is typically about a 0.03 inch clearance between bottom 130 of calibration probe 100 and the top of light pipe 40. Light pipe 40 is shown in Fig. 11 in two positions. One position has its top surface 41' close to calibration probe 100 and the other position has its top surface 41" further from calibration probe 100. Light emerges in a beam 140 from channel 110 with a spread angle α of about 90°. The exact angle α , of course, depends on the length and diameter of channel 110 and the position of LED 115 inside cavity 104. It is desirable that bottom 130 of calibration probe 100 be close enough to surface 41' so that the coverage of beam 140 will not expand to an area that is larger than the top surface of light pipe by the time it reaches light pipe 40. In other words, calibration probe 100 should be close enough to light pipe 40 so that light pipe 40 captures substantially all of the light coming from calibration probe 100. If that condition is satisfied, the temperature probe will be relatively insensitive to small changes in distance and alignment

between calibration probe 100 channel and light pipe 40. In contrast, if calibration probe 100 is too far from light pipe 40 (e.g. more than about 0.1 inches for the described embodiment), as indicated by surface 40", then the coverage of beam 140 will be larger than the diameter of light pipe 40", which consequently will only capture a fraction of beam 140. The fraction which it captures will be quite sensitive to both alignment and the distance between calibration probe 100 and the reflector plate.

To calibrate pyrometer 50, disk 150 is lifted by handle 160 and placed in chamber 60 so that projections 156 fit into lift pin holes 67. Calibration probes 100 are fit into small holes 154, LED 115 is activated, and the temperature sampled by pyrometers 50 is recorded. The uncalibrated measurements are compared to the black-body temperatures instruments 100 are known to simulate.

Another embodiment of the alignment tool which is also used for *in situ* calibration is shown in Fig. 11. Alignment tool 200 is partially integrated with a calibration probe 180 that is of a slightly different design than the previously described calibration probe. In this case, calibration probe 180 is a cylindrical tube of uniform diameter throughout (i.e., without the narrower cylindrical region 132 shown in Fig. 5). Two alignment pins 185 project away from bottom surface 130. Pins 185 slide into corresponding holes 187 located in the surface of reflector plate 20 on both sides of light pipe 40. When pins 185 are inserted into matching holes 187, channel 110 is aligned with light pipe 40. In this embodiment, calibration probe 180 is about 1.5 inches long and 0.5 inches in diameter and pins 185 are each 0.30 inches long and 0.024 inches in diameter.

An embodiment which is used to calibrate temperature probes that have been removed from the RTP system is shown in Fig. 12. In this embodiment, the calibration probe is replaced by a fixture 190 which has a cavity 191 in which LED 115 is mounted. Fixture 190 also includes a conduit 192 which aligned along the axis of cavity 191 and sized to receive a light pipe 40 for calibration. A wall 195 with a narrow aperture 197 separates cavity 191 from conduit 192. Aperture 197, like channel 110 in the previously described embodiments, allows light from LED 115 to pass through into conduit 192 where the light pipe that is being calibrated is located. The rest of the calibration probe including the electronics and the temperature stabilization circuitry are as previously described.

A method for calibrating pyrometers 50 using the above-described embodiments is shown in Fig. 13. First, a reference pyrometer is calibrated to correctly read black body temperatures (step 200). This can be done with the assistance of a standards organization, such as, for example, the National Institute of Standards and Technology (NIST) which has available calibrated sources for generating an accurately known black-body radiation spectrum for a given temperature. The reference pyrometer is calibrated to produce an accurate

temperature reading from the black body reference standard.

With an accurately calibrated reference pyrometer, the effective black-body temperature T_{eff} that is generated by a calibration instrument is then measured (step 205). Note that it is likely that each calibration probe will simulate a slightly different black body temperature due to differences in electronics, the positioning of LED 115 inside chamber 104, etc. Thus, each calibration probe should be measured individually and labeled by the temperature which it simulates. For example, one calibration probe 100 might simulate 843°C; whereas, another calibration probe might simulate 852°C.

The calibration probe can be labelled in a number of ways. A label with the simulated temperature might be directly affixed to the probe. Alternately, the probe might be affixed with a part number, code, or other identifying marker. In this case, the part number, code, or identifying marker might be indexed to the simulated temperature in a separate list.

The calibration instruments are then used to calibrate the uncalibrated thermal probes (step 210). Specifically, using the alignment tool, the calibration probe is aligned with the light pipe 40, the LED 115 is activated, and a temperature T_m that is produced by the pyrometer 50 is read.

Finally, the gain of the pyrometer is adjusted to produce a measured temperature T_m that equals T_{eff} , i.e., the black body temperature that is simulated by the calibration probe (step 215).

In summary, the reference pyrometer is calibrated to the standard at the NIST, the calibration probes are calibrated to the reference pyrometer, and the pyrometers are calibrated to the calibration probes. Therefore, the calibration of the pyrometers may be traced back to the standard. Since the standard is an accurate black body temperature source, the pyrometer temperature measurements are also accurate.

In the case of *in situ* calibrations, the calibration instrument can also be used to detect when thermal probes within a chamber have gone out of calibration due to particle contamination, drifting electronics, or whatever. The measured temperature T_m from the calibration probe can be compared with the known effective temperature T_{eff} of the calibration probe. If the difference $T_{\text{eff}} - T_m$ exceeds a predetermined threshold, the thermal probes can be cleaned, recalibrated, or simply replaced.

Other embodiments are within the scope of the following claims. For example, though the above-described embodiment used an LED as the light source, other stable light sources, such as a laser diode with appropriate stabilization control circuitry, can be used.

Claims

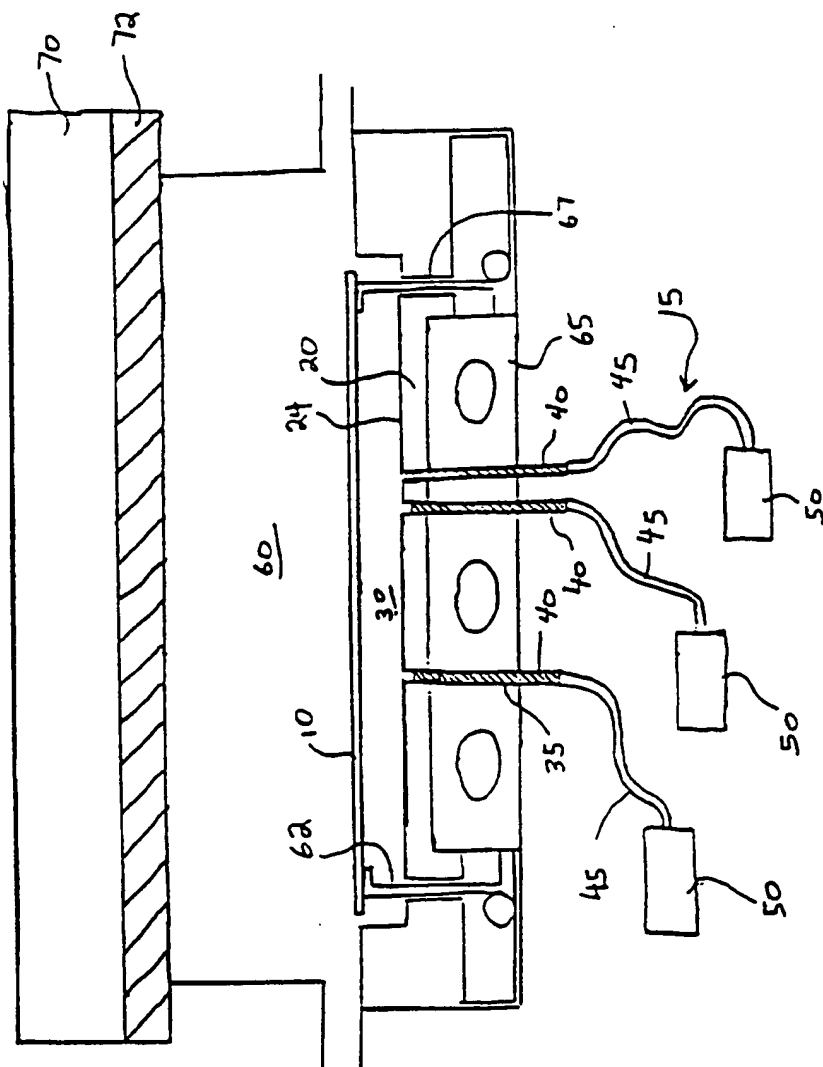
1. An apparatus for calibrating a temperature probe inside a thermal processing chamber, comprising:

- (a) an alignment tool including a cavity and an aperture leading thereto, said alignment tool further including a first alignment structure to engage a corresponding first alignment feature of said chamber; and 5
- (b) a light source having a stable intensity held in said cavity and positioned to emit light through said aperture during calibration; wherein
- said aperture is located in a position relative to said first alignment structure so that during calibration said aperture is aligned with an input of said probe. 10
2. The apparatus of claim 1 wherein said first alignment structure is a pin adapted to fit a pinhole in a reflector plate in said chamber, said pinhole located in proximity to said input end of said probe. 15
3. The apparatus of claim 1 wherein said first alignment structure is a projection adapted to fit a lift pin hole in a reflector plate in said chamber. 20
4. The apparatus of claim 1 wherein said cavity and aperture are located in a body and said body includes a second alignment structure to engage a corresponding second alignment feature of said alignment tool, said aperture located in a position relative to said second alignment structure so that during calibration said aperture is aligned with an input of said probe. 25 30
5. The apparatus of claim 4 wherein said body is removable from said first cavity. 35
6. The apparatus of claim 5 wherein said body is cylindrical, said second alignment feature is a cylindrical conduit having an annular lip, and said second alignment structure is a bottom surface of said cylinder to catch against said annular lip. 40
7. The apparatus of claim 6 wherein said alignment tool is a disk and said second alignment feature comprises a conduit through said disk. 45
8. The apparatus of claim 7 wherein said first alignment structure is a plurality of projections adapted to fit a plurality of lift pin holes in a reflector plate in said chamber. 50
9. An apparatus for calibrating a temperature probe outside a thermal processing chamber, comprising:
- (a) an alignment tool having a cavity and an aperture leading thereto, said alignment tool having an alignment structure to engage an input end of said probe; and 55
- (b) a light source having a stable intensity held in said cavity and positioned to emit light through said aperture during calibration; wherein
- said aperture is located in a position relative to said alignment structure so that during calibration said aperture is aligned with said input end of said probe.
10. A method of calibrating a temperature probe inside a thermal processing chamber, comprising:
- inserting an alignment tool having a cavity and an aperture leading thereto into said chamber; engaging an alignment structure of said alignment tool to an alignment feature of said chamber to align said aperture to an input end of said probe; and emitting light having a stable intensity through said aperture.
11. A method of calibrating a temperature probe outside a thermal processing chamber, comprising:
- removing an input end of said probe from said chamber; engaging an alignment structure of an alignment tool having a cavity and an aperture leading thereto to said input end of said probe to align said aperture to said input end of said probe; and emitting light having a stable intensity through said aperture.
12. An apparatus for calibrating a temperature probe inside a thermal processing chamber, comprising:
- (a) a calibration probe including a cavity and an aperture leading thereto, said calibration probe further including a light source having a stable intensity held in said cavity and positioned to emit light through said aperture during calibration; and
- (b) an alignment tool for aligning said calibration probe, said alignment tool including a first alignment structure to engage a corresponding first alignment feature of said chamber; wherein
- said aperture is located in a position relative to said first alignment structure so that during calibration said aperture is aligned with an input of said temperature probe.
13. The apparatus of claim 12 wherein said probe is removable from said alignment tool.
14. The apparatus of claim 12 wherein said alignment tool is integrated with said calibration probe.
15. An apparatus for calibrating a temperature probe outside a thermal processing chamber, comprising:

- (a) a calibration probe including a cavity and an aperture leading thereto, said calibration probe further including a light source having a stable intensity held in said cavity and positioned to emit light through said aperture during calibration 5
- (b) said alignment tool having an alignment structure to engage an input end of said temperature probe; wherein
- said aperture is located in a position relative to said alignment structure so that during calibration said aperture is aligned with said input end of said temperature probe. 10
16. An apparatus for calibrating a temperature probe that measures a temperature of a substrate during processing within a thermal processing system, comprising: 15
- a calibration tool having a cavity and an aperture leading thereto; 20
- a light source having a stable intensity located in said cavity and positioned to emit light through said aperture during calibration; and 25
- an alignment mechanism to align said aperture to an input end of said probe during calibration.
17. The apparatus of claim 16 wherein said light source is a light emitting diode (LED). 30
18. The apparatus of claim 17 further including a feedback circuit to stabilize the light output of said LED.
19. An apparatus for calibrating a temperature probe that measures a temperature of a substrate during processing within a thermal processing system, comprising: 35
- a calibration instrument including a light emitting diode having a stable intensity held in a cavity and positioned to emit light through an aperture into an input end of said temperature probe during calibration, said calibration instrument emitting light having a predetermined intensity; and 40
- an indicia indicating a temperature from a black body that said light of having said predetermined intensity emitted by said calibration instrument simulates. 45
20. A method for calibrating a temperature probe that measures a temperature of a substrate during processing within a thermal processing system, comprising: 50
- using a calibration instrument, including a light emitting diode, which emits light having a predetermined intensity that simulates radiation from a black body at a temperature T_0 ; 55

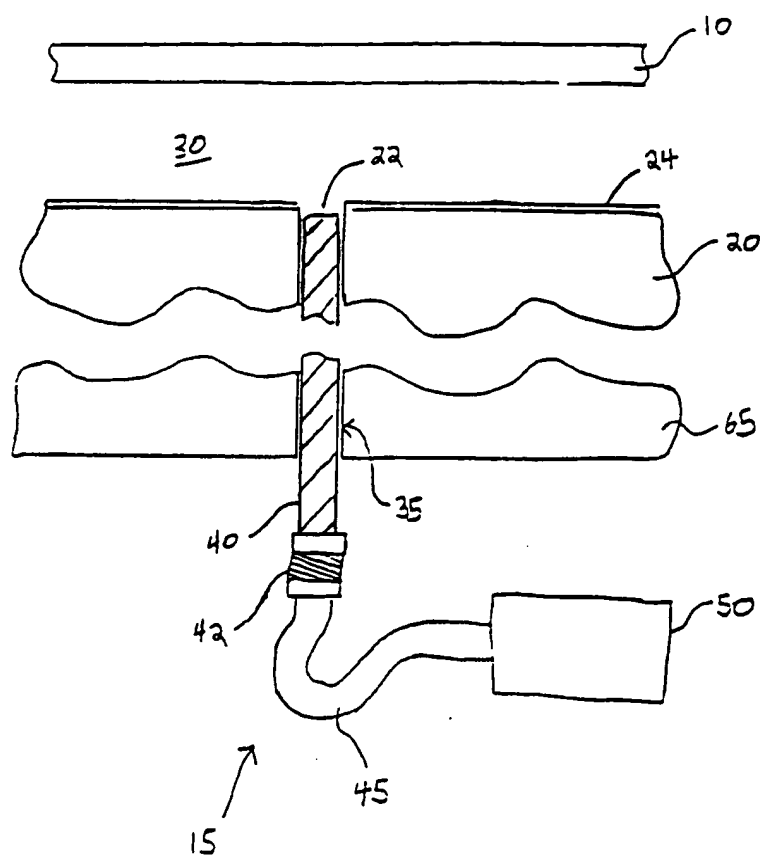
shining said light into an input end of said temperature probe while said calibration instrument is emitting said light having said predetermined intensity;

using said temperature probe to produce a temperature reading T_1 in response to said light having said predetermined intensity; and using the difference between T_0 and T_1 to generate corrected measurements from said temperature probe during processing within said thermal processing system.



1561

FIG. 2



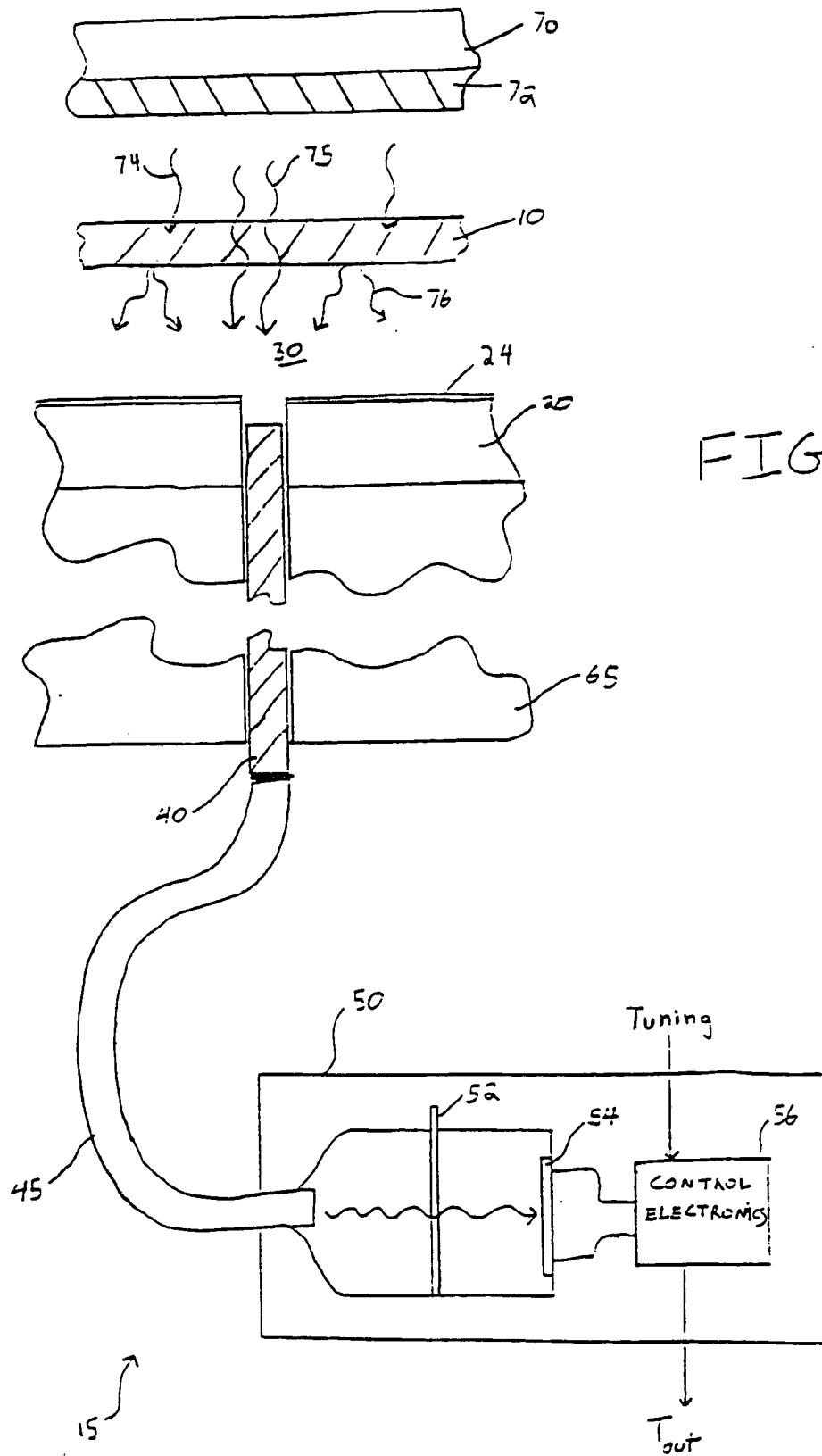
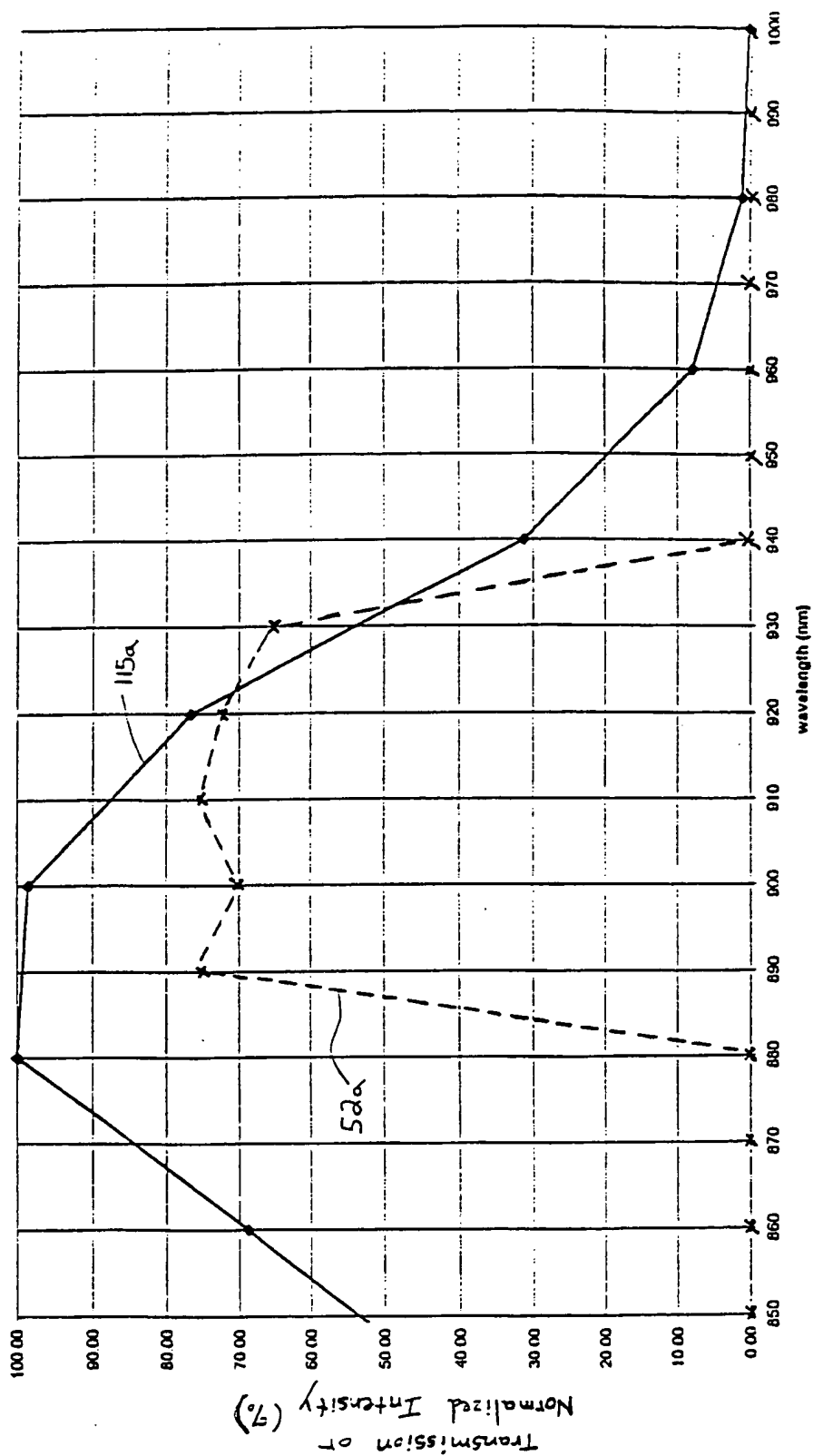
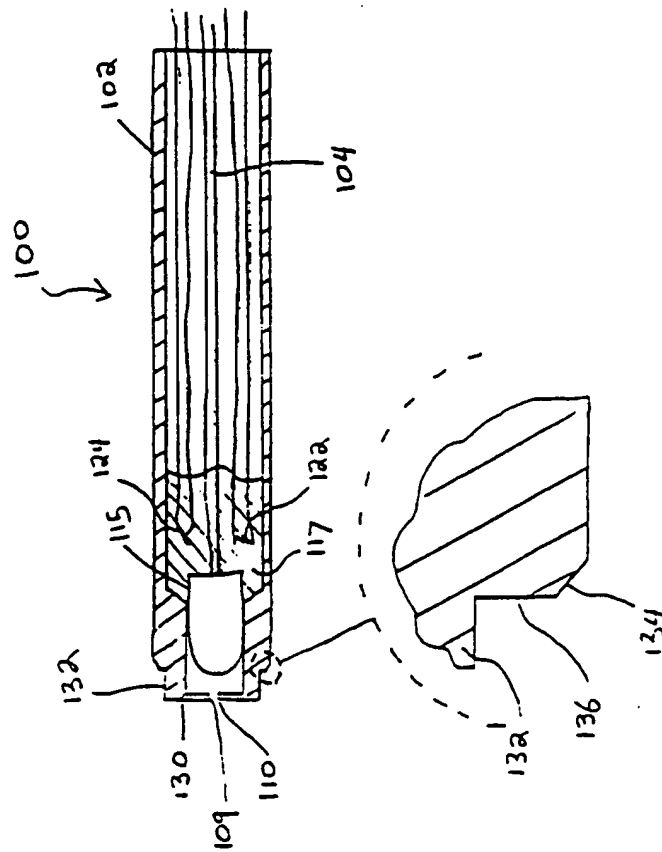


FIG. 4





LGTH

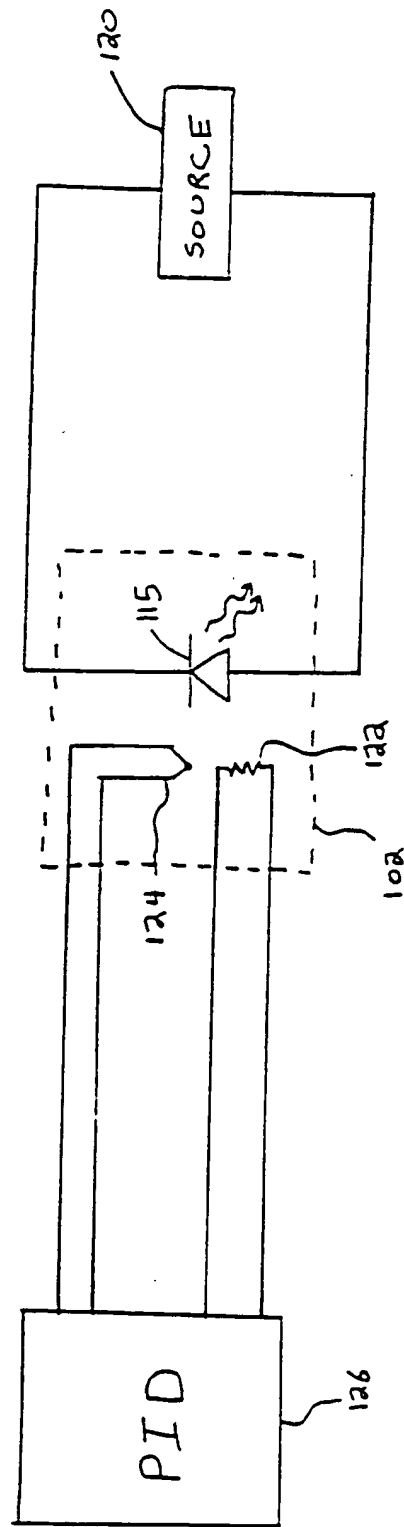


FIG. 6

FIG. 7

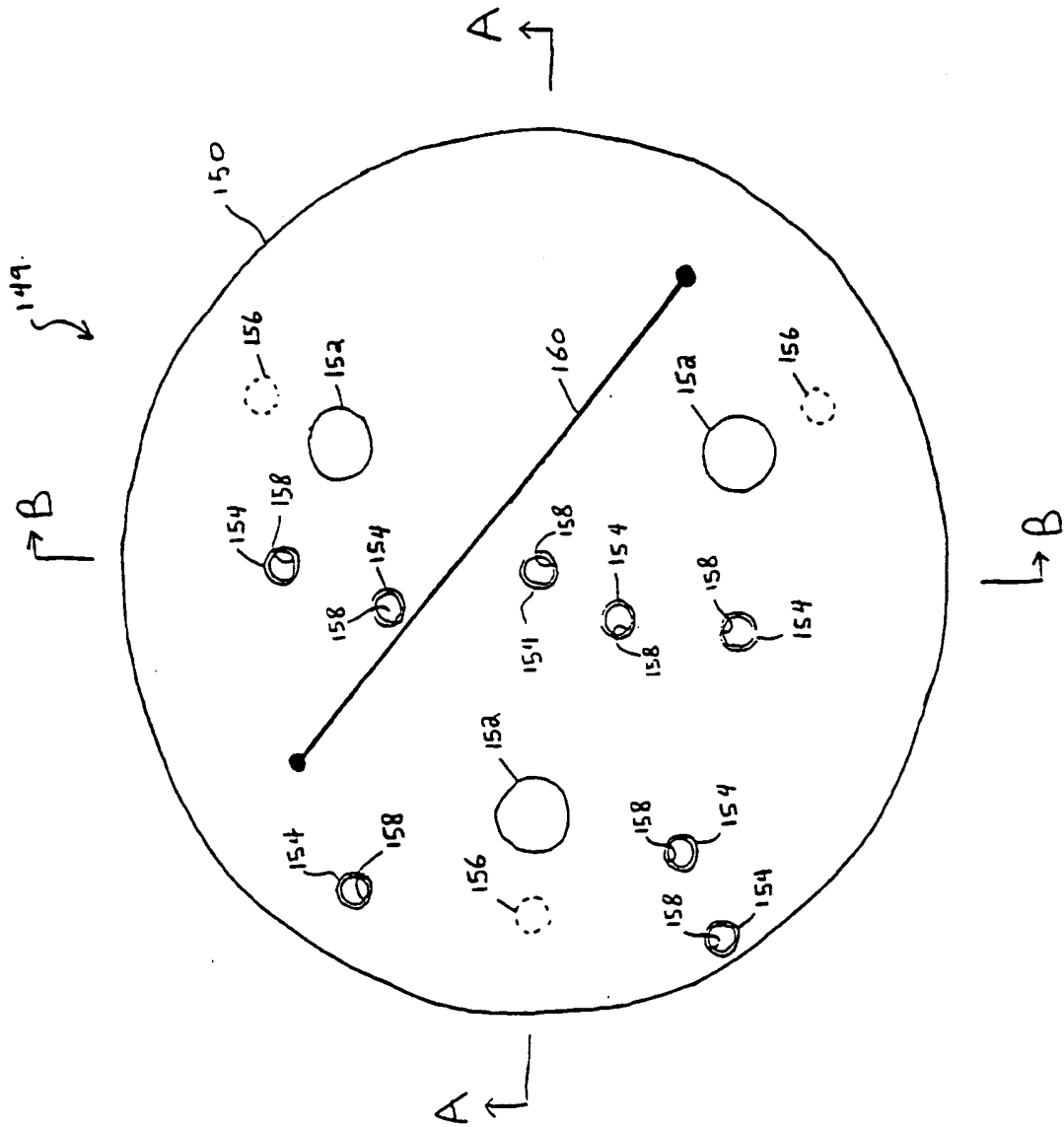


FIG. 8A

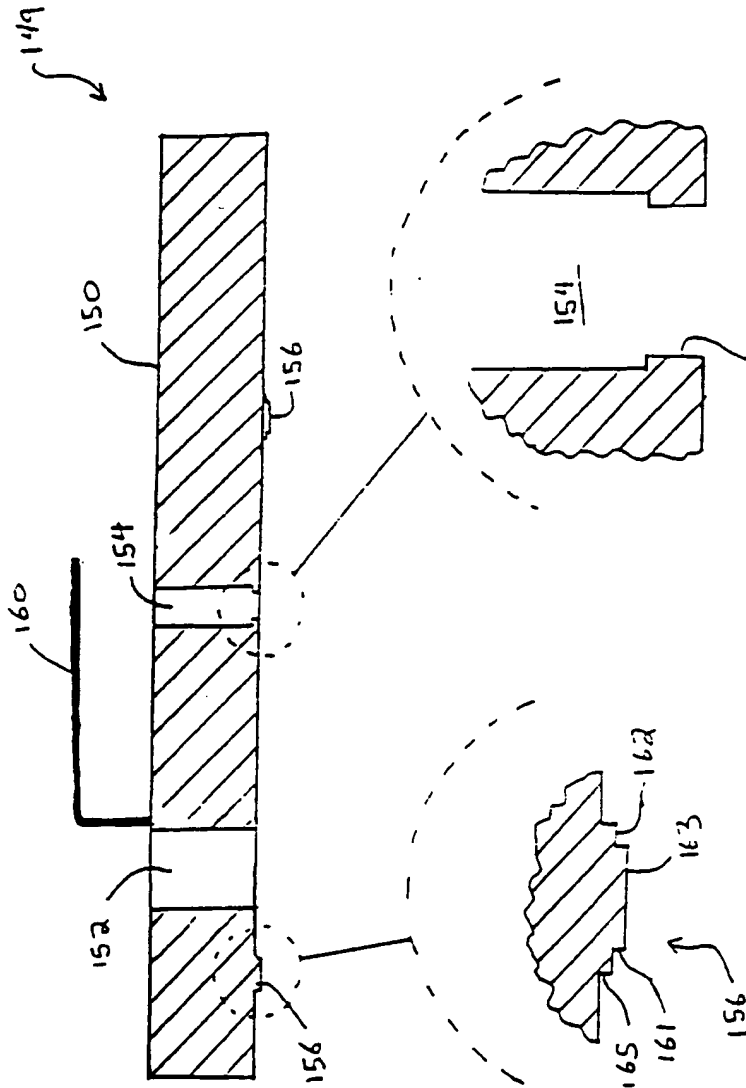
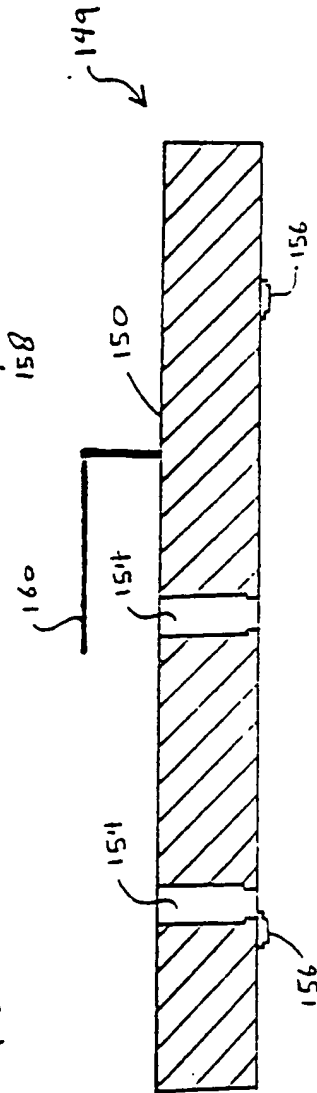
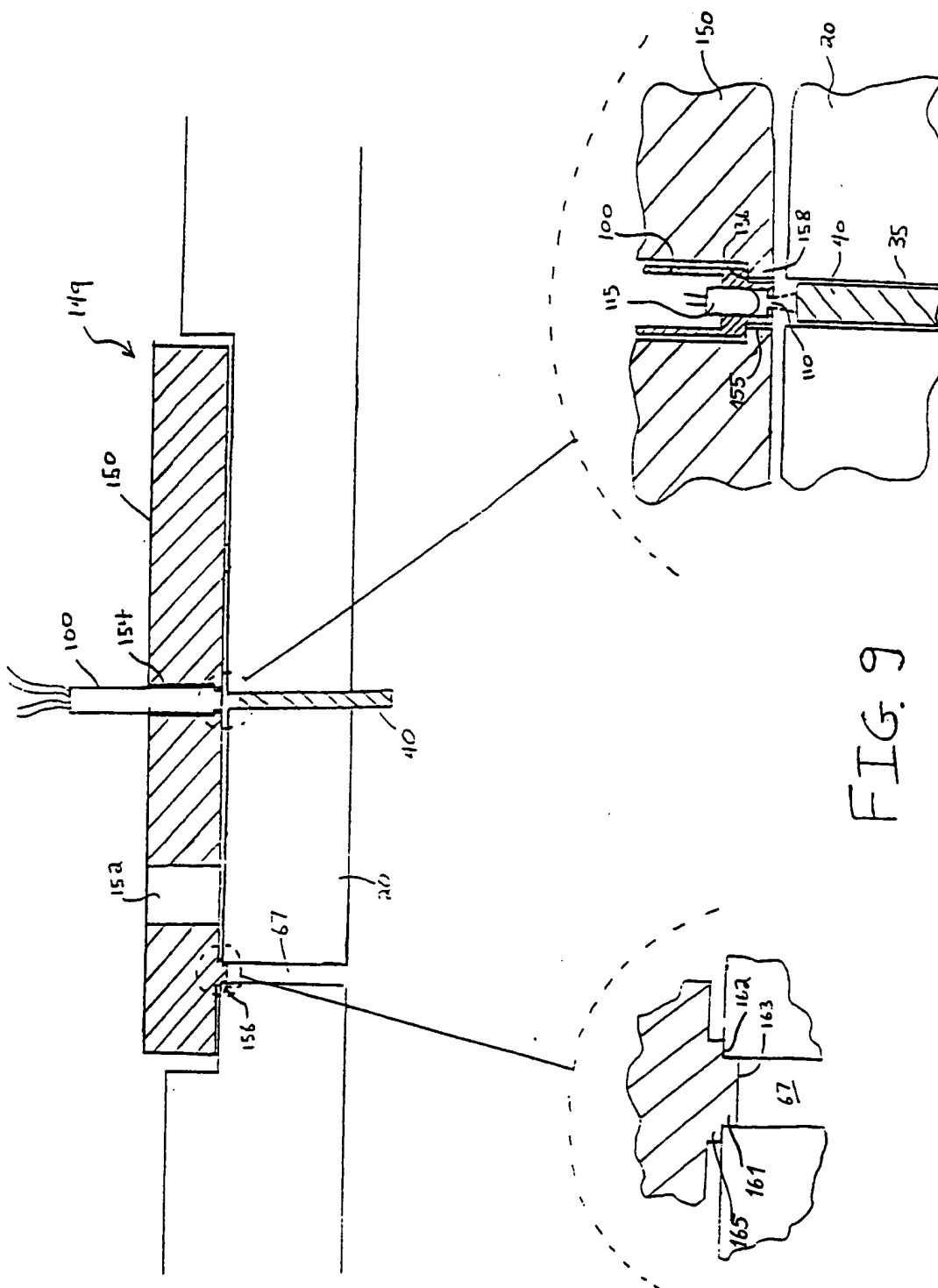


FIG. 8B





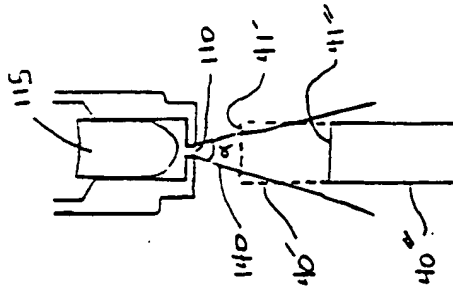


FIG. 10

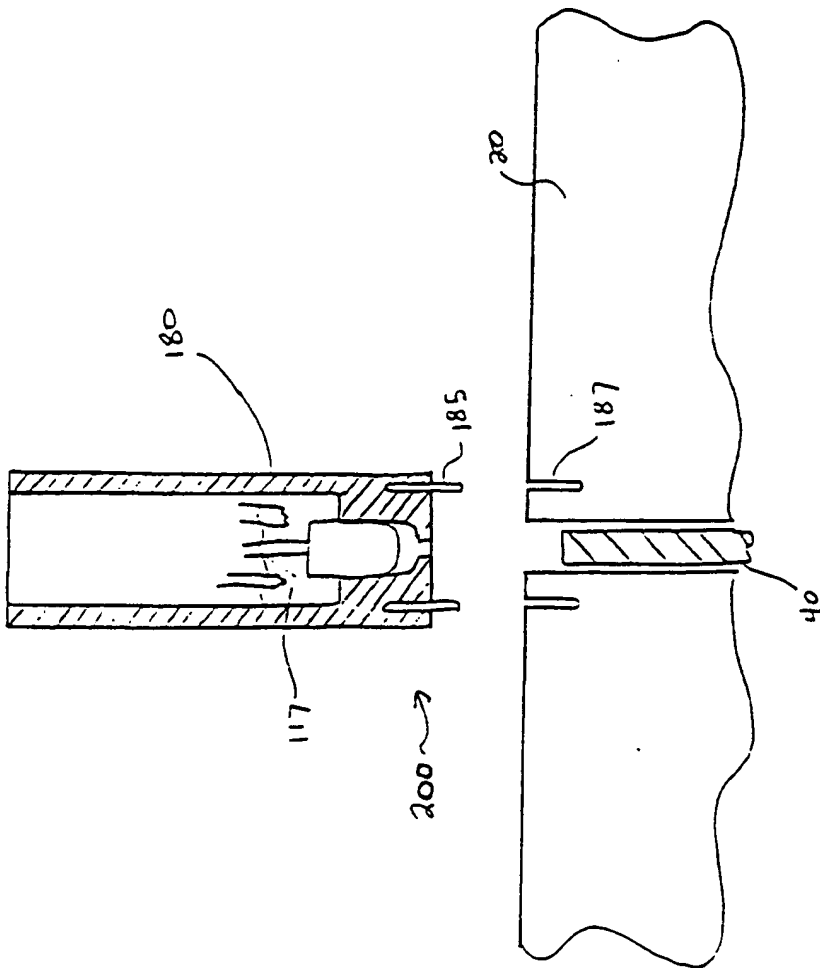


FIG. 11

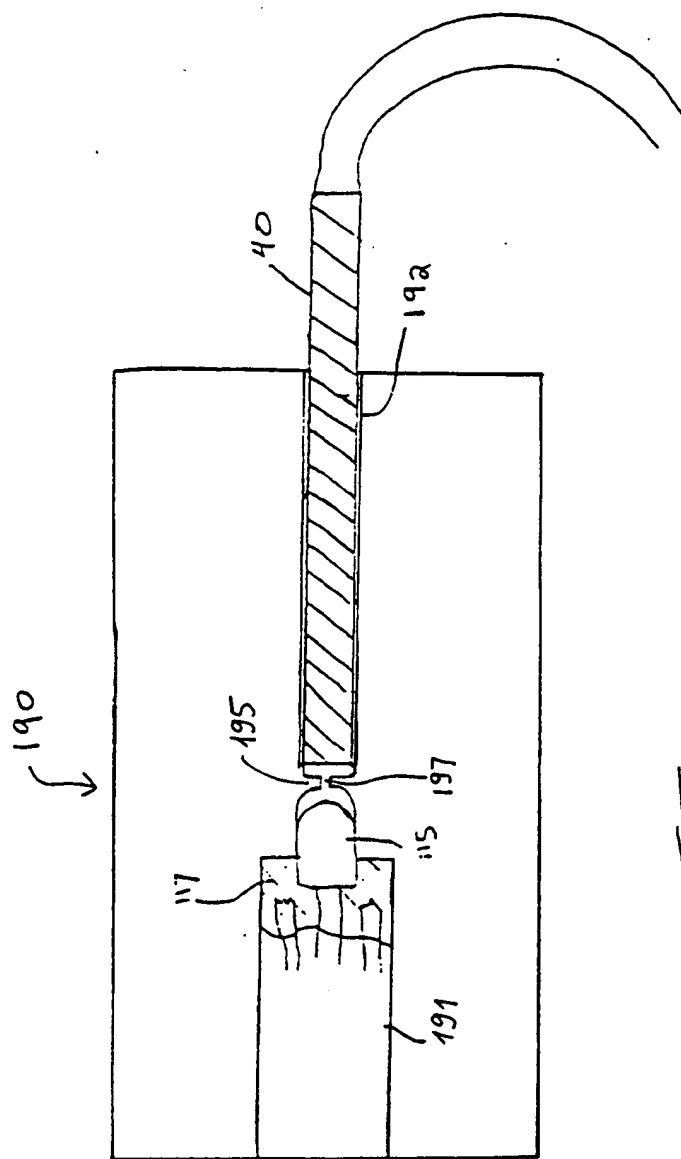
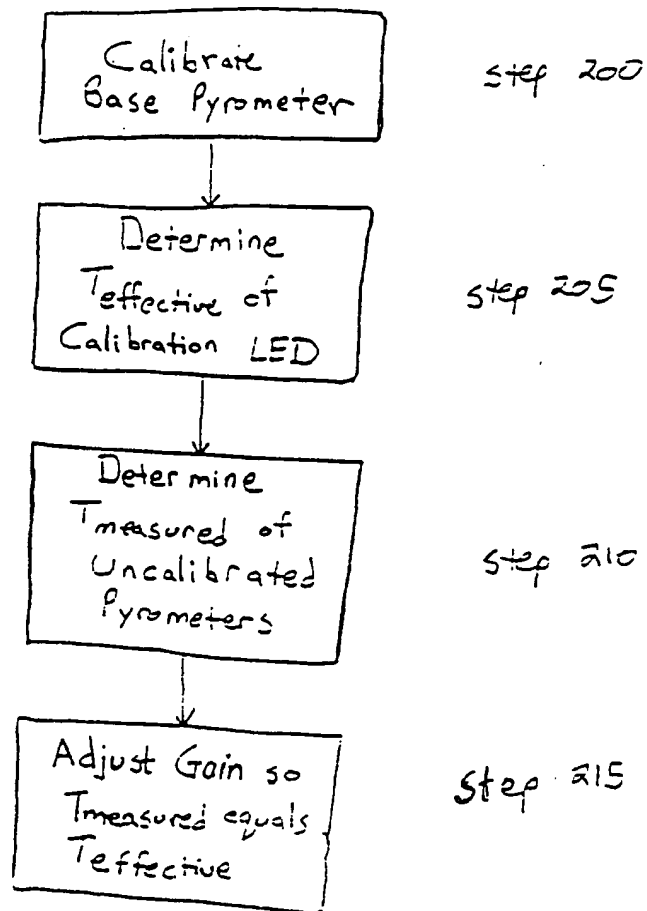


FIG. 12

FIG. 13





European Patent
Office

EUROPEAN SEARCH REPORT

Application Number
EP 96 11 2107

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	PATENT ABSTRACTS OF JAPAN vol. 011, no. 201 (P-590), 30 June 1987 & JP 62 022036 A (FURUKAWA ELECTRIC CO LTD:THE), 30 January 1987, * abstract *	15	G01J5/52 G01J5/00
A	---	1,5, 9-14,16, 17,20	
A	US 5 265 957 A (MOSLEHI MEHRDAD M ET AL) 30 November 1993 * column 1, line 23 - column 2, line 36; figures 4,8 *	1,9-11, 15,16, 19,20	
A	---		
A	US 5 324 937 A (CHEN WALLACE W ET AL) 28 June 1994 * column 3, line 41 - column 4, line 12; figure 2 *	1,9-12, 15,16	
A	---		
A	DE 32 21 382 A (LAND PYROMETERS LTD) 23 December 1982 * page 7 - page 9; figure 1 *	1-6	TECHNICAL FIELDS SEARCHED (Int.Cl.6) G01J
The present search report has been drawn up for all claims			
Place of search BERLIN		Date of completion of the search 18 November 1996	Examiner von Moers, F
<p>CATEGORY OF CITED DOCUMENTS</p> <p>X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document</p> <p>T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons ----- & : member of the same patent family, corresponding document</p>			